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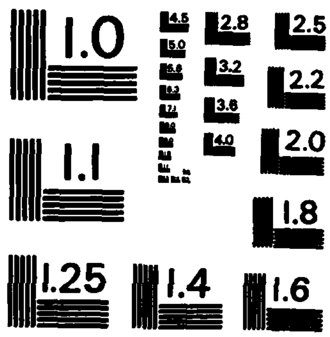

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Aerodynamic Considerations in Open Shelters

Robert G. Hickman

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Prepared for the Federal Emergency Management Agency
Washington, D.C. 20472
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Final Report, November 1984

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Aerodynamic factors are addressed bearing on the suitability of open structures as blast shelters. Blast closures and attenuator designs are discussed. The research on shelter filling is reviewed; this includes both experimental and theoretical work on scale models and full-scale structures of large dimensions. Shock-dominated and pressure-gradient-dominated shelter-filling mechanisms are described and their potential effects on people are discussed.

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AERODYNAMIC CONSIDERATIONS IN OPEN SHELTERS

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Summary

Aerodynamic factors are addressed bearing on the suitability of open structures as blast shelters for people during a nuclear attack. The designs and performances of blast attenuators and closures are important because they determine the extent to which a structure is open.

Modes of structure filling (shock-driven or pressure-gradient-driven) are described in terms of theoretical calculations and experimental investigations on full- and fractional-scale models of structures. Potential lethality mechanisms resulting from these structure-filling modes are discussed.

This report concludes that small, open structures in an as is condition will be filled rapidly by the shock that enters the structure. For sufficiently weak shocks, there may exist some safe zones from the structure-filling modes, depending on the number, location, and size of openings, as well as on the number of rooms, and the proximity of objects that might be hurled at people during the blast.

Large, open structures, on the other hand, will probably fill more slowly by pressure-gradient-driven flow. The fill times for small and large shelters can vary by more than a factor of 10, and can be as great as hundreds of milliseconds for a large shelter. The winds associated with pressure-gradient-driven structure filling can be lethal. Therefore, determining safe zones is a difficult, though probably not impossible, task.

It is recommended that open structures not be used as blast shelters, except as an interim measure, if alternatives are available.

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INTRODUCTION

Ways to protect people from the effects of nuclear explosions have been studied for more than 30 years. Early on, Civil Defense workers realized that protection would not be easy (or cheap) to accomplish.

A great deal of work has been performed on research directed toward development of protective structures. Some structures were for protection of military equipment, but most were for protection of personnel, either military or civilian. In this report attention is mainly on shock/blast effects on a class of structures known as "open shelters." An open shelter is simply a shelter with one or more "fixed" openings which admit shock and blast effects; closed shelters have no such openings. To be useful of course, closed shelters must have some openings, but they are ones that can be shut before much of the shock front enters the shelter. At present, closed shelters are generally not available for civilian protection.

In actuality, even closed shelters show some blast leakage effects because closure mechanisms are imperfect in terms of response time and seal quality. And some open shelters can be fitted with shock and blast attenuators. Consequently, there is an almost continuous spectrum of "degree of openness" of shelters. A very brief review of this spectrum will be given before we focus our attention on open shelters. All structures (e.g., basements) are open unless they have been specifically designed and constructed to make them closed. At the request of FEMA, one subset of open structures, underground parking garages, will be given particular emphasis because of their large size. It is possible that, with a rather modest investment, some open structures could be made into potential, interim blast shelters. This would be a cost-effective way to provide some protection.

Underground parking garages are seldom more than three levels deep because of their construction costs; it is less expensive to build upward from ground level than it is to dig below it. Originally generated as part of the Five Cities Study, some rather outdated information exists on the amount of underground parking space available, its locations, its costs, and the numbers of persons having access to it.[1]

The goals of this review were to evaluate existing, open structures that might be used as shelters, of which underground parking garages could be a

major component. Emphasis was to be given to those topics dealing with gas dynamics and shelter filling, with special consideration to jet flow phenomena. Assumptions and limitations were to be identified and experiments suitable to be performed at the Ft. Cronkhite shock tunnel were to be identified. Expedient measures to improve the protective capabilities of these garages were to be suggested if they came to mind. In what follows, it is assumed that the structure does not collapse. Structural response is not part of this scope of work.

CLOSURES AND ATTENUATORS

This brief section is included because retrofitting some existing underground garages might make them more acceptable as open shelters. Also, any new garages built with shelter as a possible use could include such devices. Discussion here serves principally as an entry vehicle into the existing literature.

Closures for a shelter are usually put on openings that serve one of three functions: personnel entry, space ventilation, and combustion air/exhaust for emergency generators. For an underground garage, entry and exits are through three natural routes: automobile entrances and ramps (open), stairways (usually enclosed), and elevators (always enclosed).

First consider elevators. During an emergency, use of elevators would be discouraged. They have neither the reliability nor the capacity to be useful for speedy occupation of shelter space. Besides, the elevator doors on each level are flimsy, as is the elevator compartment. Nevertheless, the elevator shaft is of substantial cross-section and usually goes to all levels in a structure. To minimize blast entering via it, the elevator shaft could be partially "plugged" by placing the elevator at the upper-level opening (the one least suited to shelter use anyhow) and filling the compartment with as much mass as possible. Even with gravity assist in accelerating the elevator downward, external overpressures will have dropped substantially before the elevator reaches the lowest (and safest) level--thus reducing blast entry.

Stairways and stairwells pose a similar problem of allowing blast entry during an attack, but they may be needed as exits later--depending largely on

efforts made to close the auto entrances if the structure is a garage. Stairwells could be fitted with blast doors. Some experimental tests on steel blast doors to various overpressures were part of the Smoky event (43 kT) of Operation Plumbob[2,3] in 1957, and a very elegant theoretical analysis on the static and dynamic performance of flat blast doors is available. Round steel plastic-yielding membrane doors also have been studied for quite a while.[4]

Other blast doors are currently under development as part of the Key Worker shelter program. Some doors were tested in the Direct Course event, and others have been tested at the Ballistics Research Laboratory recently.

An expedient method to keep an existing door in place or to partially block a doorless opening in the stairwell would be to load a van as full as possible and back it against the door. Two heavily loaded vans in tandem would be even better. They would at least partially block the blast. A caution must be raised. If an elevator shaft or stairwell with walls of unreinforced masonry is "stoppered," its walls could literally explode, with the resultant hazard of flying debris to persons nearby. Also, the advisability of placing a vehicle containing gasoline in the direct path of the blast needs additional investigation.

Closure for the final personnel entry in a garage structure, the auto ramp, has been designed and tested.[5]

The amount of work done on closures for ventilation of space or equipment is substantial. Many clever mechanical and electromechanical devices have been designed and tested.[6-9] They are fairly reliable in function when new, but their reliability will surely decrease over a long period of time, due to accumulation of dirt and corrosion. Regardless, they frequently still leak when new, and even small leaks can cause injury to someone close to and in the path of the leak.[10] The mechanisms of this leak process will be described more fully when "jet flow" is discussed.

In addition to the efforts on closing the openings, work has been performed on shock and blast attenuators. Shock attenuators are usually shock randomizers (using shock reflections), although flow restrictors are also used. Multiple-reflection tunnel passages and ventilation ducts have been described and tested.[11-14] Perforated steel plates, staggered arrays of baffles and tubes, and rock filters use both techniques.[8,12,15] Some shock attenuation has been demonstrated in long small-diameter tubes without

resorting to reflections, although it was not intended to provide protection by itself.[16] Although little effort has been devoted to shock-absorbing linings, in the tests that have been performed they were found to be rather ineffective.[17,18]

STRUCTURE FILLING - GENERAL

The shock front arriving at an open structure will move into it through the openings. Immediately behind the shock front, the air has a characteristic particle velocity, which can be thought of as a shock-produced wind. If the structure doesn't collapse, the shock propagates into it through the openings, expands to fill it, and is reflected from its walls. Rarefaction waves, constructive and destructive interference of shocks, and eventual dissipation of the shocks are observed. As the fronts move about within the structure, they are followed by their respective characteristic particle velocities.

If the area of the openings is small relative to the volume of the structure, the shock-produced wind will be accompanied by pressure-induced wind caused by the higher pressure outside the structure. That both the shock and the induced winds can cause fatalities has been an important datum for 30 years.

Exposure, in air, to a shock front with an overpressure greater than 28 psi can cause death from damage or destruction of tissues at gas/solid interfaces inside the body, as in the lungs and the gastrointestinal tract.[15] The lethality depends on the shock overpressure and, to a lesser extent, its rise time.[10] Consequently, both propagation of shocks inside structures and structure filling (with air) have been studied experimentally and theoretically.

The follow-on winds can also cause death. Depending on their speed and duration, they can tumble people, hurl them against objects, or hurl objects into them. Death comes from the injuries caused by the various impacts. The relationship between shock strength and particle velocity is well-known and easily calculated from the equations of one-dimensional gas dynamics. A good general reference on weapons effects[19] or introductory gas dynamics[20] is

all that is needed. These wind-related kill mechanisms would probably be common for nuclear weapons because of the usual long duration of the positive pressure phase which leads to long duration winds. In an open structure, the winds induced by the inside/outside pressure difference can be even more hazardous, again because of their high velocity and long duration.

STRUCTURE FILLING - SHOCK-DRIVEN

In some of the earliest tests, it was observed empirically that damage to the interior of underground open structures was proportional to the size of the opening.[2] Since the structures did not fail structurally, the damage was not caused by the pressure increase itself, but rather by the winds associated with the blast as described. Obviously, as the number and size of openings in a structure decrease, the structure approaches the closed condition which provides the best protection.

Experimentally, much work was done using scale models and shock tubes. Whenever a scale model of an open structure or a full-scale, small open structure is used, the filling is dominated by shock interactions and the associated particle velocity. General population personnel shelters are usually not expected to provide protection above 15 psi maximum overpressure but other special purpose shelters can go to much higher pressures before they fail. For example, at 50 psi or less, the normal shock velocity, or Mach number, is then 1.98 or less and the particle Mach number is 0.58 or more, if air is treated as a perfect gas.[20] At standard conditions, this would correspond to a shock maximum velocity of a little more than 660 m/s. If the scale model has dimensions on the order of 0.1 to 1 m, then the shock would traverse the interior of the structure in 0.15 to 1.5 ms. Weaker shocks would travel more slowly, but in no case would the shock Mach number drop below 1.0. Thus, the whole event is over in a very short time period (3 ms).

Shock propagation through various openings in small models was measured with a shock tube. A reduction in the amount of pressure that would be developed in the structure interior was found.[21] Shock reflection off the entry-tunnel walls was believed to be an important factor. The same general approach on the filling of one- and two-room scale-model (0.1 m dimensions)

structures was used, but this time the results were compared with larger models (approximate 1 m dimensions) exposed to the blast from a chemical high explosive.[22]

Agreement was reasonable for these simple geometries when the observed results were restricted to pressure rise inside the models. Although oscilloscope records showed fluctuations in the filling rate, they were smoothed for convenience in data interpretation. Smoke was used to obtain some information on velocities, but three-dimensional effects had to be ignored. Also, spark shadowgraphs were made to follow the movement of smoke into the model for a 10-ms duration. Some parts of the space gave better protection than did others, depending on the model's orientation relative to the shock front's direction of approach. Schlieren photographs were made that showed the complexity of shock wave interactions within the model. The observations were all nominally two-dimensional.

An interesting addition to the methods for inferring velocity inside structures was used in operation Prairie Flat, in which wire-solder drag gages were used.[23] The structure was small (largest dimension 3.5 m), with a standard-size door in the wall facing the 500-ton chemical explosive charge. After the explosion the wires were bent. The amount and direction of bending suggest something about the flow field. Changes in wind directions could not be inferred, of course, and the response of the wire drag gages to a changing flow field differ after their initial deformation. Even so, it was an interesting experiment and provided qualitative information on shock-dominated filling.

Small scale models tested with shock tubes showed a reduction in final internal pressure attained and an increase in the rise time to this pressure when both an attenuator was fitted to the entrance and the entrance was to an anteroom (acting as a plenum) rather than to the main room.[24] In this particular test, the dominant mechanism of fill is a bit unclear, so its applicability to a full-scale structure is uncertain. The small model, compared with the relatively long fill time (200 ms), strongly suggests that conventional flow was a major contributor. This inference is strengthened by the observation that filling is shock dominated when more than 10-15% of the exterior wall is open.[25]

The first serious attempt to understand the differential loading on a structure that results from "slow" shelter filling was performed at BRL.[26] Again, it was a small scale model (dimension <1 m) with a sizable opening facing the shock front. The new element introduced in this work was studying the pressures on the walls in three dimensions. Numerical calculations of the loads were performed, and a greater appreciation for the complexity of shockwave interactions and their influence on structural loading was gained. It was determined that the experimental program would be enhanced if larger models were used. However, emphasis continued to be restricted to shock fronts and their interactions; 20 shadowgraphs were obtained. Vortex development was observed.

Almost without exception, workers have used simple geometries and assumed that the shock front approached structure openings either side-on or at normal incidence. Even given these simplifications, however, it is still very difficult to exactly predict even shock-dominated structure filling; there is no general description. That the results so obtained cannot be expected to scale to full-size structures was first mentioned by Melichar in an insightful review.[27] For example, in a simple symmetrical two-dimensional structure with a single floor-to-ceiling entrance facing the approaching shock front, there are six interacting waves involving 22 independent variables that must be described for a reasonable period of time. Although it might be possible to solve this problem (i.e., calculate the filling theoretically), it would have no relationship to anything real or useful.

An attempt was made to calculate the velocity field (rather than filling time) in a simple scale model. The model was 0.1 m x 0.1 m with a 25 mm entrance facing a normal shock. This put the filling process near the transition region between shock-dominated and non-shock-dominated filling, if Melichar's assertion is correct. Two-dimensional calculations were done for 10-psi and 20-psi shocks, with and without a baffle wall just inside the front entrance,[28] using the RIPPLE computer code.[29] From the predicted velocities, it appears that shock interaction is either not included or else it has a negligible effect. For example, after 0.17 ms without the baffle, the 10-psi shock has not yet moved to the back wall. The shock does weaken (and slow) as it expands into the room, but the "infinite" reservoir of higher-pressure gas just outside the entrance supports it temporarily. In no

case should the shock speed drop below Mach = 1, so the shock should have reached the rear wall and been reflected. Therefore, we infer that shocks and their interactions probably are not part of this calculation. Simple as this calculation was, it was very useful because velocity as a function of time was calculated. It was possible then to begin thinking about velocity as a function of both time and position, so that safe and unsafe areas inside the scale model could be defined.

Shocks and their interactions inside shelters can be calculated in three dimensions using the HULL computer code, which was developed in 1971 and had undergone 100 revisions by 1980.[30] HULL can calculate local dynamic pressure neglecting, as usual, viscosity. Neglect of viscosity introduces only small errors except along walls or in corners. More interestingly, though, after an internal flow field is developed within a shelter (with very high local velocities possible), there is nothing to slow the created winds. With a peak speed of 400 mph lasting for several milliseconds, calculations suggest that everything capable of being moved follows the stream lines and eventually reaches this speed. In actuality, however, the winds do slow, because viscous drag is not zero. Consequently, calculated instantaneous peak velocities must be examined carefully when we are interested in human lethality.

Other computer codes that are used in conjuction with HULL are LAMB (a shock generator) and KEEL (a grid/mesh generator).[31]

STRUCTURE FILLING - PRESSURE-GRADIENT-DRIVEN

The filling of underground garages or other large volume structures is probably not shock-dominated. The typical wide automobile entrances (one to four lanes) will definitely allow the shock front to enter in a major way. Still, we can turn to the empirical assertion that openings constituting 10% or less of the perimeter wall will change the dominant mechanism from shock dominated to pressure-gradient dominated.

For a multistory underground garage, the shock will weaken on the first level as it expands and encounters pillars and interior walls. Only a small fraction of the original shock front would propagate (greatly weakened) to the

second level, most probably having turned one or more corners and undergoing another large expansion as it enters the second level. It appears that no shock wave that does not destroy the garage in the first place will make it to the third level underground, but high winds will still be present in some areas even on this level. In addition, if the structure is not destroyed, it is unlikely that smaller internal structural components such as columns would be.

Pressure-gradient-driven shelter filling has been termed "jet flow" as a matter of convenience. Theoretical treatments have often started with "jets" because the original inrush of air behind the shock front is described with classical orifice (or nozzle) equations, which are isentropic one-dimensional compressible flows. These jets can reach high speeds although they are limited in size. As the jets mix with the air in the structure, the pressure rises; more important, potentially dangerous secondary flows also develop, and they can encompass much larger flow volumes than the initial jet.

This phenomenon (with the given gross approximations), has been simple enough to treat analytically, in contrast to the complex interactions of several shock fronts inside a structure. One of the earlier papers[32] predicted that the pressure reached in a structure of simple geometry could be given by

$$P = \frac{380\ P_0 A D_t}{V}$$

where

P = maximum internal pressure

P_o = overpressure at the shock front

A = structure's opening area (ft^2)

V = structure's volume (ft^3)

D_t = duration of the positive phase (s).

It is hard to find a simpler expression. However, the pressure reached is of relatively little concern to shelter planners; the important thing for them is local time-dependent air velocity. A similar treatment for postblast leakage of closure valves was tested experimentally and gave acceptable results,[6] but the valves were not part of a shelter.

As the filling occurs, the pressure outside the shelter declines but remains higher than that inside. Eventually, once the filling is complete, the pressures inside and outside will become equal at the entrance to the shelter. Then as the positive pressure phase continues to decay, the pressure outside falls below the pressure inside, and the flow at the entrance reverses direction. As air flows out of the structure, winds persist inside. Eventually, after about 10 s, pressures inside and outside the structure return to ambient and the winds cease.

A more elaborate treatment of orifice flow is available and acknowledges some of the difficulties in trying to use simple formulations.[33] In it is considered the difficult regime of structure filling when both shock effects and pressure-gradient-driven flow are important. A lengthy list of references on the subject is given. Choked-orifice flow (when the pressure ratio is less than 0.528) and coupling of the jet flow to the structure's air are also considered. The 0.528 absolute pressure ratio indicates that an initial overpressure above 13.1 psi will produce a shock at or just inside the orifice (structure entrance) that will temporarily limit the maximum mass flow rate of air into the garage. This author concluded, after a substantial one-dimensional theoretical development, that confidently defining safe zones in an open structure was not yet possible.

Another good discussion of the transition from shock flow to jet flow includes the application to small basement shelters.[34] Two two-dimensional computer models, PIC and FLIC, were evaluated for predicting structure filling. The models were less than successful, principally because they ignore turbulence and viscous shear effects that can be substantial in a small enclosed space. (Turbulence is both a dissipative factor and a means of momentum transfer from the highspeed flow to stagnant regions of the shelter.) Despite that, the models have more application to small structures than large ones. One conclusion was that smaller entries give longer fill times (desirable effect) but higher local flow velocities (an undesirable effect).[34] (This was contradicted by later work.[35]) Another important conclusion was that jet flow would be responsible for most fatalities, the reason being that at shock overpressures of 15 psi or less, the jet flow is faster than the shock particle velocity and the jet flow lasts longer.

Pressure-gradient-dominated structure filling, like shock-dominated filling, was of interest. In an approximate treatment based on orifice flow, the investigators concluded that winds in chambers other than the first would still be severe.[36]

In general, the emphasis was on fill times and maximum pressures rather than on the definition of safe areas, a limitation inherent in all one-dimensional treatments. Perhaps this was to see if the fill time would be short enough to prevent structural collapse from the inside/outside pressure difference.

An interesting pair of scale-model studies were done in which perimeter and volume of the model structures were made very much larger than the single opening.[37] The shock penetrated the opening, but it had to expand so much it appears to have never reached the other walls and been reflected. The positive phase was long enough to establish a pressure-gradient-driven flow that reached high speed and, in turn, induced secondary flow throughout the volume of the model. The shock front passed the opening side-on, and a few hundred milliseconds were required to raise the scale model to its maximum pressure. Local velocities were predicted with the RIPPLE code, and small nylon cylinders placed in the model were accelerated to substantial velocities.

In scaling up these results to a full-scale structure, it was believed that real cylinders would have achieved only half the velocity measured in the experiment.[37] A 170-lb cylinder was predicted to reach no more than 12 fps from a 1-MT blast at the 5-psi maximum overpressure distance in this shelter. While viscosity and drag effects were ignored or treated very lightly, this was one of the most interesting simulations that had been done, even though it was a very simple geometry. It demonstrated an increased concern for what truly was important: people. A computer simulation was less successful in predicting filling for full-scale structures.[38]

One of the difficulties with using a one-dimensional orifice and its equations to describe the flow of air is that there is always present a dimensionless coefficient that must be evaluated experimentally. This is true even when the orifice is perfectly round and the wall in which the opening exists is thin. In practice, even these two conditions are seldom met. Fortunately, the numerical value of this dimensionless coefficient is almost always between 0.5 and 1.0, so use of 0.8 is common practice.

More rigor can be brought to the problem if the analysis is based on the behavior of a nozzle. Obviously, square windows and automobile ramps are not nozzles, but at least we are able to predict how an ideal nozzle would behave without resorting to coefficients that cannot be calculated. Development of the pertinent equations are in several reports mentioned next and won't be repeated here. The developments with the most clarity are to be found in texts on gas dynamics rather than in technical reports.[39,40] Adaptations and approximations for applications to hypothetical structures are found in reports to be described in the next section.

Most authors treat nozzle flow as a steady-state or quasi-steady-state problem, just because it is easier. Actually, we could expect a reasonably smooth increase and decrease in internal shelter pressure, as mentioned earlier. The transient pressure influence external to the large structures has been treated for nozzle flow.[41] Internal pressure fluctuations in small structures have been attributed to Helmholz-like resonator effect.[25] This occurs when the internal dimensions and shock velocities are such that reflected shocks can interfere in a manner that produces regular pressure and shock-driven flow fluctuations.

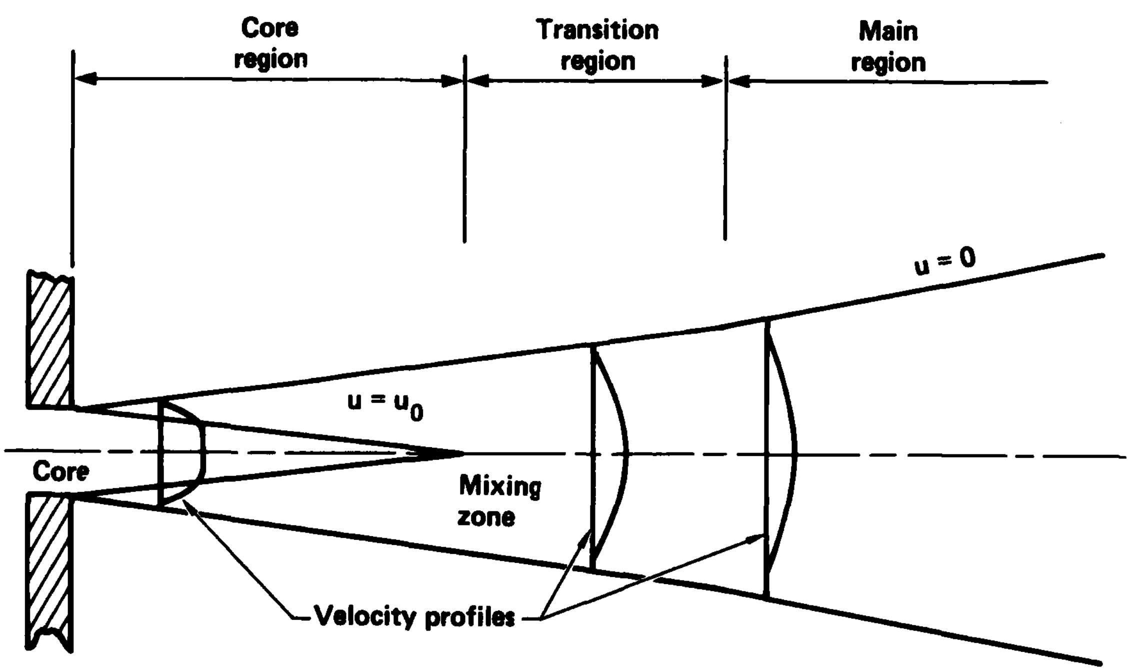

Figure 1. Jet flow characteristics (Ref. 42).

In an idealized way, an air jet entering a structure can be shown in two dimensions schematically as in Fig. 1.[42] In a large structure, such a jet could almost fully develop before the initial shock front even has time to propagate to the rear of the structure. The very high-velocity core region reaches several opening diameters into the structure, and the average speed within the core is uniform and calculated to be equal to that predicted by the adapted one-dimensional nozzle equations. The core mixes turbulently with the other air, forming a broader, lower velocity jet that still has boundaries for a while and for some distance.

Outside the mixing zone, the air is not yet involved. Flow from the turbulent main region eventually involves the entire structure's air volume to a greater or lesser extent. It has been suggested that internal flow durations do not exceed twice the fill time and that the fill time in milliseconds is given by $(V/A)x10^{-3}$, where V is structure's volume (ft^3) and A is the structure's opening area (ft^2). Some authors multiply by a factor of 1/2, but either must be regarded as only an approximate rule. The fill times have never been measured or calculated for the kinds of structures in which we are interested.

For large internal/external initial pressure differences, a shock develops just inside the opening (choke condition) for initial overpressures greater than 13.1 psi. This limits the flow rate to Mach 1, but the speeds are still far above those required to be lethal. A lethal wind is one that can accelerate a penetrating or nonpenetrating missile, or a person to a speed such that impact can cause death. These speeds are given in tabular form in Ref. 19. The velocity profiles shown in Fig. 1 were calculated, but they do not apply quantitatively to real openings in a real structure. They do provide some physical insight. More information on turbulent jets is available.[43]

Of some interest is the idealized jet's core velocity. This is shown in Fig. 2 (from Ref. 44) and compared with the velocity of the shock front and with its associated particle velocity. The values are those calculated from the classical equations. The break in the curve for the jet velocity occurs at the critical pressure ratio. Note that up to rather high shock overpressures (40 psi), the initial jet core velocity exceeds the particle velocity associated with the shock front.

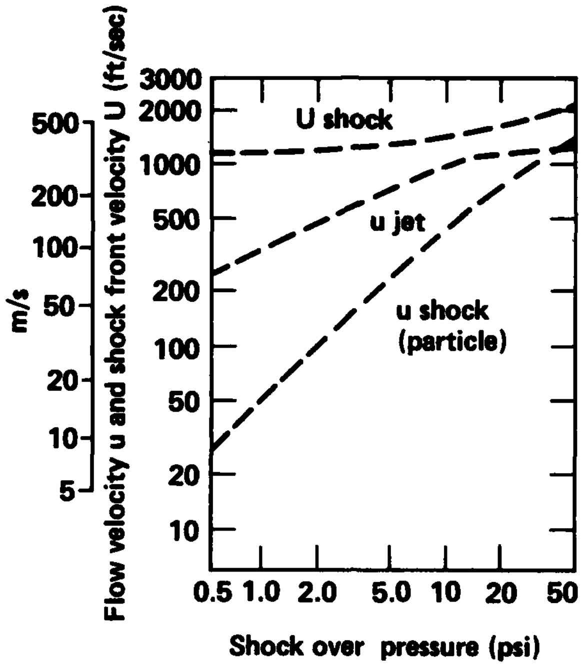

Figure 2. Shock and jet parameters (Ref. 44).

As the literature on structure filling increased, it generally came to be understood that personnel in large open shelters were not likely to be killed by the sharp pressure rise associated with arrival of the shock front or by the pressure rise from the filling process. Neither were they likely to be thrown about a lot by the strong winds immediately behind the shock, because of its short duration. Lethality is more likely to result from long-duration, high-velocity winds that arise from and include jet flows associated with pressure-gradient-driven shelter filling. This phenomenon is amply described[25,45] and only a few highlights will be presented here. (In Ref. 25, see Appendix D by P. Strom.)

The closer workers came to answering the important question about survival, the greater were the assumptions they had to make. The question of what happens to a real person in a real shelter at a logical location could not be answered confidently. Estimates on time of exposure to winds capable of displacing a person varied by a factor of 30.[25] Personnel can reduce their aerodynamic drag coefficient by lying down (see Fig. 3), but safe areas could not be defined.

Death upon impact with another object was predicted for a man initially standing at the six-psi overpressure distance in the core of a jet produced by a large explosion. Death would not be as likely if the same person were sitting, unless he moved in toward ground zero to the 12-psi contour. This is another example of the importance of reducing one's drag coefficient as much as possible if the winds cannot be avoided.[46]

One study represented the human body as a rigid rectangle that can tumble and bounce, and gave 54 ft/s as the 50% lethality speed for whole-body impact. In the same study a more complicated analysis, using an articulated representation of the body, gave a 50% lethality speed of 18 ft/s for head impact and 23 ft/s for whole-body impact.[36]

These figures are for impact with a hard, unyielding object such as a wall or a floor. However, in a structure filled with people, a hurled body might very well strike other bodies instead of walls and floors. The probability of surviving the blast would therefore improve.[46] Likewise, if basements had padded walls and floors, they would be suitable as shelters.

After a time-dependent velocity field for a shelter interior was calculated, it was usually assumed that a person would be accelerated by its entire duration. The fact that during the acceleration time the person would move to a different orientation (with a different drag coefficient) and a different location (with a different wind velocity time history) had to be ignored. Dynamic pressures, accelerations, and finally body velocities were usually calculated using crudely estimated time averages of changing variables. Usually the Friedlauder relation is used to infer the velocity change caused by late-time dropping external (to the shelter) pressure. This is a double exponential expression that adequately predicts the decay of pressure behind a shock front in a free-field environment. In one study, the total flow history was calculated by separating it into four, separate time intervals that could each be treated in a simplified way. In this fashion the entire time history could be represented.[35] This approach made a unique contribution, even though the methods used for the separate time intervals were the same as those employed by other workers.

Characteristically, as individual projects would draw to a close, the researchers would make guesses about what might be inferred on the basis of

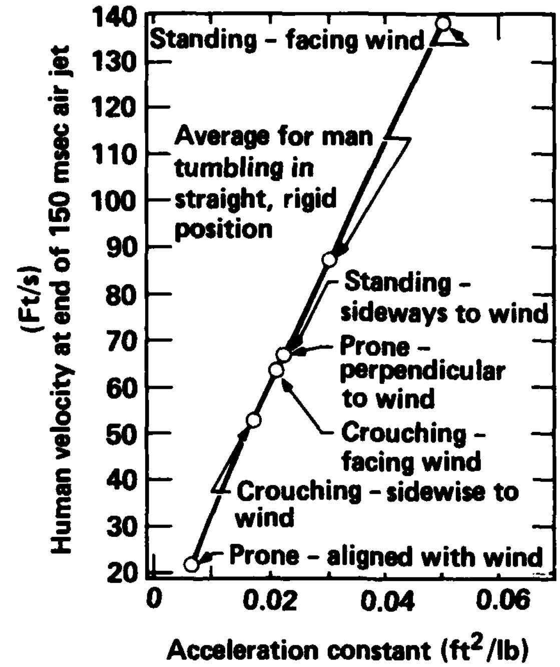

Figure 3. Velocity vs. acceleration constant for 168-lb human male under transient air flow (no friction) (Ref. 25).

their work. These guesses usually were never explored to the point that conclusions could be drawn confidently.

It is recognized that friction with the floor would slow persons being blown about, and tumbling would also change the acceleration results. But both of those could themselves cause serious injury.[45] Calculations of translational velocities and trajectories of the bodies of people who sought shelter in open structures showed that it was much safer away from the openings and in the corners of the room (where it is assumed there are no openings). Generally, these calculations were for hypothetical, residential-basement size rooms. By invoking symmetry arguments, a larger, hypothetical structure with multiple entries was reduced for calculational purposes to a set of smaller structures. When tumbling considerations and differences in body shapes and sizes were taken into account, they were found to have relatively little impact on mortality. For areas exposed to high

winds, most impacts in larger structures were expected to involve persons' heads hitting the floor, rather than a wall, at lethal velocities.[35] Some medium-scale tests at the Ft. Cronkhite shock tunnel suggested that avoiding the jet core would by itself give survival rates of 90% or more, but that was for short-duration flows into a rather small shelter.[26] These guesses cannot be confidently extrapolated to a blast wave of 30 times the duration and a shelter with 300 times the volume.

One of the more interesting analyses considered moderate shock pressure (13.1 psig max.) with small (basement) single and multiple rooms. Methods for hand-calculating multiple connected chambers were given. Small openings were postulated so structure fill times would be fairly long. The usual analysis based on isentropic nozzle flow was included. The unique features about this work were its consideration of turbulent jets and the extensive explicit consideration of the time dependence of the flows on their lethality to people.[45] In this latter regard it was one of the few that addressed the issue of protection. Use of constant momentum flux in a turbulent jet is discussed in an earlier reference.[44]

In Fig. 1, it will be noted that the turbulent jet can be considered to diverge continuously from a virtual source several aperture diameters outside the shelter. The transverse velocity gradient is given approximately by a cosine-squared function, and longitudinal velocity drops inversely with distance from the virtual point of origin. Aerodynamic drag effects were based on time-averaged velocities during moderate time intervals, but the treatment was two-dimensional assuming a round aperture. Such a treatment requires that the exterior "reservoir" have no interfering structure between the virtual source and the aperture or immediately adjacent to the aperture. In a parking garage, that could require ceilings 70 ft high, which is an impossible requirement. Thus, the analysis is flawed. Still, it is one of very few reports to mention and treat turbulent jets. Again, artificial constraints had to be imposed to render the problem tractable. Within these constraints, the authors concluded that only persons in the first room of a multiroom basement shelter would be killed by the jet. This was based on people being hurled against an unyeilding object. Impact velocity threshold for mortality of a "standard person" was taken to be 21 fps.[19]

The problem faced is enormously complicated; almost without exception, researchers pointed out the limitations and assumptions that had to be made to gain the understanding we now have. It is false to say we know nothing; we know a great deal. When the bulk of the work was terminated about 15 years ago, however, we did not know enough to confidently evaluate individual shelters. And it was known--from the work of many diligent people--that there were no "general rules" that could be universally applied.

In a major compilation of reports on structural design for dual-purpose use, underground garages are explicitly mentioned, and the problems of jet flow are discussed.[42] (Figure 1 is taken from Appendix E of this work; this appendix by J. Rempel is one of the best summaries for structure filling for large structures.) The report analyzes a real underground parking structure, with three levels (two levels underground) at the courthouse plaza in Columbia, Georgia. It is of reinforced concrete construction. The underground ceilings are each about ten feet high, and the deepest level has an area of 68,000 ft^2; the ceiling of the first underground level is at street level. It has four large ramps for cars plus several stairwells and elevators for pedestrians. The shelter space was planned to be the two sublevels. The authors concluded that without blocking off ("blast closures") the pedestrian entries, there was little if any safe area for a person to take refuge because high speed winds were predicted to fill almost the entire three-level structure. If the pedestrian entries were blocked off, most of the first sublevel (the middle level) was still not safe but about 80% of the lowest level was judged to be safe from blast (jet flow) effects with a 20 psi shock. Jet effects were calculated with information and methods that were then available, but the calculations were finally abandoned in favor of engineering judgment to define safe zones.

SUMMATION

In this review, we have addressed open shelters in general with some special attention being given to underground parking garages in the central business districts of major urban areas. We reviewed closure and attenuation devices because blast entry into large very open structures renders

them largely useless for shelter purposes, quite apart from their inherent weakness (which is not part of this scope of work). This last statement must be qualified though, because a few persons with enough foreknowledge could seek shelter in an underground garage and be better off than if they were standing outside during a nuclear attack. A full-scale hardened underground garage was built for the purpose of shelter and tested at the Nevada Test Site.[5] It survived 40 psi nicely, and a 50-psi capability was expected. It was not cheap, however, so we have none in our inventory today.

Most of the research effort on open structures has been directed at understanding blast entry. It occurs by shock-dominated processes at the earliest times. Immediately after this (in large shelters), high-speed flows develop from the substantial pressure difference between the interior and exterior of the structure. This is the dominant fill mechanism for large structures and the one that probably would cause most of the prompt deaths if the structure didn't collapse. The underlying theory is well understood but has found little application to real structures. This has resulted partly from the inherent three-dimensionality of all real structures and also from the rather puny computational capabilities that were available when this large body of work was brought to a close.

The chances that some people will be killed by structural collapse and that others will be killed by blast entry associated with the collapse have been considered using existing data.[47] These results are interesting but of limited value to the present study, which stipulates that there will be no structural collapse.

Requirements for environmental control (temperature and CO_2 accumulation), structural survival of the shelter, and shelter stocking with water, etc. are not part of this scope work,[4,8,25,46,48]

CONCLUSIONS

All topics in the assigned scope of this work, with the exception of the Ft. Cronkhite experiments discussed in the "Recommendations" section, have been discussed in the text. The understanding of jet flow was limited by researchers' inability to treat complex models in three dimensions. The bulk of the analyses were limited to hand calculations of isentropic flow in one

dimension; usually only subsonic flow was treated. More elaborate computer models exist now for application to real structures, but they tend to be shock interaction codes. Each existing structure needs to be treated individually before it can be considered a shelter. Actually, the researchers got a lot of insight from fairly rudimentary considerations, but when put to the test, the analysis of a real structure was based on engineering judgement rather than on a set of calculations. Obviously some more sophisticated calculations could be done today. Also, we can surmise that in a very large structure (such as a garage), shock propagation within the garage and into lower levels of it plays a negligible role. However, safe zones cannot be confidently designated.

RECOMMENDATIONS

The shock tunnel at Ft. Cronkhite would not be appropriate to supply an "infinite" reservoir of high-pressure gas to simulate the overpressure from a large nuclear explosion. However, the blowdown facility at Ft. Cronkhite might be. Large sized scale models of real structures could suddenly be surrounded with an overpressure of 15 psi that slowly decayed to ambient. The exit to the outside would have to be throttled, of course. Internal (to the structure) time-dependent flow velocities could be measured for estimating safe zones. For underground garages this could be both with and without scale-model cars present. Three-dimensional aerodynamic calculations on real structures are needed to define safe zones and thereby save lives because calculations will be cheaper than experiments after the computer software is developed. Until this work is completed, open structures should not be recommended as blast shelters. Walls and perhaps floors should be covered with soft material if it is practical. These recommendations do not consider the other aspects of survival in a shelter.

REFERENCES

1. C. McGavin, "Shelter Potential in Parking Garages," Applied Parking Techniques, Inc., Reston, VA. Report No. APT-1170, November 1970. DTIC Acc. No. AD 715 416.
2. L. Vortman, "Evaluation of Various Types of Personnel Shelters Exposed to an Atomic Explosion," Sandia Corporation, Report No. WT-1218, May 1956, DTIC Acc. No. AD A 073 524.
3. E. Cohen and A. Bottenhofer, "Test of German Underground Personnel Shelters," Civil Effects Test Group, Rpt. WT-1454, June 1962, DTIC Acc. No. AD 691-407.
4. L. Dresner, "Annual Civil Defense Progress Report," Oak Ridge National Laboratory, Report No. ORNL-TM-1531 Part 1, Nov. 1966; DTIC Acc. No. AD 802-519.
5. E. Cohen, E. Laing, and A. Bottenhofer, "Response of a Dual-Purpose Reinforced Concrete Mass Shelter," Ammann & Whitney, AEC Report No. WT-1449, Sept. 1962, DTIC Acc. No. AD A 073 525.
6. R. Kiang, "Blast-Actuated Closure Valves for Personnel-Type Shelters," Stanford Research Institute, Report No. 4949-211, February 1967, DTIC Acc. No. AD 661 648.
7. E. Cohen and S. Weissman, "Blast Closure Systems," in the Proceedings of the Symposium on Protective Structures for Civilian Populations, Washington, D.C., April 23-25, 1965, by National Research Council June, 1966, DTIC Acc. No. AD A951-921.
8. C. Beck, ed., "Nuclear Weapons Effects Tests of Blast Type Shelters," U.S.A.E.C., June 1969, Document No. CEX-68.3, DTIC Acc. No. AD 691 184.
9. J. Kessler and L. Levoy, "A Study of Blast Closure Devices," American Machine and Foundry Co., Report AFSWC-TDR-62-10, February, 1962, DTIC Acc. No. AD 274 646.
10. D. Richmond, E. Fletcher, K. Saunders, J. Yelverton, "Injuries Produced by the Propagation of Airblast Waves Through Orifices," Lovelace Biomedical and Environmental Research Institute, Report DNA 5618 T, March 1980, DTIC Acc. No. AD A106 146.
11. L. Ingram, "Attenuation of Airblast in Protective Structures," U.S. Army Engineer Waterways Experiment Station, Report No. I-608, Nov. 1963, DTIC Acc. No. AD 450 996.

12. L. Hallanger, "Blast Attenuation Systems for Ventilation Openings," U.S. Naval Engineering Laboratory, Report No. TR-475, Sept. 1966, DTIC Acc. No. 489 392.

13. L. Dumitrescu, A. Mitrofan, and S. Preda, "Studies on Mechanical and Aerodynamical Blast Attenuation Devices," INCREST-National Institute for Scientific and Technical Creation, Bucharest, 1981, DTIC Acc. No. AD P 000 301.

14. D. Williams and R. Fashbaugh, "High Explosive Field Test of a Hardened Air Entrainment Systems," Naval Civil Engineering Laboratory, Technical Note N-1181, October 1971, DTIC Acc. No. AD 890-483.

15. D. Richmond and R. Taborelli, "Blast Biology-A Study of the Primary and Tertiary Effects of Blast in Open Underground Protective Shelters," Lovelace Foundation for Medical Education and Research , AEC Report No. WT-1467, June 1959, DTIC Acc. No. AD A 077 511.

16. G. Coulter, "Attenuation of Peaked Air Shock Waves in Smooth Tunnels," U.S. Army Ballistics Research Laboratory, Report No. BRL M 1809, November 1966, DTIC Acc. No. AD 650 741.

17. J. Norbutas and D. Pal, "Nuclear Blast Attenuation by Ventilation Duct Liners," Naval Civil Engineering Laboratory, Report No. R625, May 1969, DTIC Acc. No. AD 852 703.

18. J. Muirhead, "The Effect of Various Materials on the Reflection of Shock Waves," Suffield Experiment Station, Alberta Technical Paper No. 142, September 1958, DTIC Acc. No. AD 206 208.

19. S. Glasstone and P. Dolan, "The Effects of Nuclear Weapons," U.S. Energy Research and Development Administration, 1977. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

20. H. Daneshyar, "One Dimensional Compressible Flow," page 21, Pergamon Press, New York (1976).

21. R. Clark and W. Taylor, "Shock Pressures in Tunnels Oriented Face on and Side on to a Long Duration Blast Wave," U.S. Army Ballistics Research Laboratory. DASA Report No. 1177, June 1960, DTIC Acc. No. AD 242 793.

22. G. Coulter, "Air Shock Filling of Model Rooms," U.S. Army Ballistics Research Laboratory, Report No. BRL-MR-1916, March 1968, DTIC Acc. No. AD 670 937.

23. G. Coulter and R. Peterson, "Blast Fill Time of a One Room Structure," Ballistics Research Laboratory, DASA Report No. WT-2102, November 1969.

24. R. Medding, "Blast Effects Inside Field Shelters," U.S. Army Mobility Equipment Research and Development Center, Report No. 1988, September 1970, DTIC Acc. No. AD 877 952.

25. J. Melichar, "Analysis of the Effect of Shelter Openings on Blast Protection," URS Research Company, Report No. URS 773-6, September 1970, DTIC Acc. No. AD 724 710.

26. G. Coulter, "Air Shock Loading of Exterior Walls of Shelter Models," Ballistics Research Laboratory, Report No. 2118, August 1971, DTIC Acc. No. AD 729 775.

27. J. Melichar, "The Propagation of Blast Waves Into Chambers," Ballistics Research Laboratory, Report No. BRL-MR-1920, March 1968, DTIC Acc. No. AD 672 476.

28. G. Coulter and V. Kucher, "Computer Predictions for a Blast Wave Induced Flow in a Room Shelter," U.S. Army Ballistic Research Laboratory, Report No. BRL-MR-2544, October 1975, DTIC Acc. No. AD A 017 746.

29. M. Evans "RIPPLE - A Two Dimensional Eulerian Computer Program for Calculating Compressible Flow and Detonation Problems," General Atomic Co., Report No. GAMD-8165, September 1967.

30. M. Booen, "Airblast Propagation Within An Aircraft Shelter," Air Force Weapons Laboratory, Report No. AFWL-TR-81-15, June 1981, DTIC Acc. No. AD B 060 495.

31. J. Wortman, "Blast Computations Over a Hemishperical Aircraft Shelter," U.S. Army Ballistics Research Laboratory, Report No. ARBRL-MR-03115, July 1981, DTIC Acc. No. AD B 058 960.

32. A Chilton, "Blast Pressure Leakage Into Closed Structures Through Small Openings," U.S. Navy, Bureau of Yards and Docks, Report No. TS-23, February 1958, DTIC Acc. No. AD 244 508.

33. A. Kriebel, "Airblast in Tunnels and Chambers," URS Research Co., DNA Report DASA 1200-11 Supplement 1, October 1972, DTIC Acc. No.

34. J. Melichar, "Airblast Induced Aerodynamic Effects in Blast-Slanted Basement Shelters," URS Research Co., Report No. URS 692-3, January 1969, DTIC Acc. No. AD 691 773.

35. A. Longinow and A. Wiedermann, "Relative Structural Considerations for Protection from Injury and Fatality at Various Overpressures" IIT Research Institute, Report No. J6365, June 1977, DTIC Acc. No. A 049 040.

36. A. Longinow, "People Survivability in a Direct Effects Environment and Related Topics" IIT Research Institute Report No. J6144 May 1973, DTIC Acc. No. AD 764 114.

37. G. Coulter, "Blast Loading of Objects in Basement Shelter Models," Ballistic Research Laboratory, Report No. 2348, January 1974, DTIC Acc. No. AD 775 456.

38. C. Kingery and G. Watson, "Blast Leakage Into Hardened Aircraft Shelter Models," U.S. Army Ballistics Research Laboratory, Report No. ARBRL-TR-02392, February 1982, DTIC Acc. No. AD B 063 617.

39. R. Rotty, "Introduction to Gas Dynamics," John Wiley, New York, (1962).

40. H. Liepmann and A. Roshko, "Elements of Gas Dynamics," John Wiley, New York (1957).

41. W. Elewick, "Pressure Response Within An Enclosure Subject to a Blast Wave," Rand Corporation, Report No. RM-2660, March 1961, DTIC Acc. No. AD 256 411.

42. H. L. Murphy, et. al., Slanting in New Basements for Combined Nuclear Weapons Effects: A Consolidated Printing of Four Technical Reports," Stanford Research Institute, October 1975, DTIC Acc. No. AD A023237.

43. G. Ambraovich, "The Theory of Turbulent Jets," MIT Press, Cambridge (1963).

44. K. Kaplan, and P. Price, "Accidental Explosions and Effects of Blast Leakage Into Structures," Scientific Services, Inc., AARADCOM Report No. AD-E 400 320, June 1979, DTIC Acc. No. AD A 072 787.

45. H. Childers, C. Vansant and D. Mokrauer, "Open Shelter Feasibility Study," The Vertex Corp., Report No. TR-68-1, October 1968, DTIC Acc. No. AD 688 659.

46. A. Longinow, J. Kalinowski, C. A. Kot, and F. Salzberg, "Civil Defense Shelter Options: Deliberate Shelters, Vol. II," IIT Research Institute Report No. J6144 December 1971, DTIC Acc. No. AD 740 175.

47. A. Longinow, "Probability of People Survival in a Nuclear Blast Environment," IIT Research Institute Report No. IITRI-J6479-FR, May 1980, DTIC Acc. No. A 087 600.

48. A. Longinow, T. E. Waterman, and A. N. Takata, "Assessment of Combined Effects of Blast and Fire on Personnel Survivability," IIT Research Institute Report No. J 6483, June 1982.

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